

# Uncertainty and Sensitivity Analysis in the 2008 Performance Assessment for the Proposed Repository for High-Level Radioactive Waste at Yucca Mountain, Nevada

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# Outline

- **Description of the proposed Yucca Mountain Repository**
- **Summary of regulatory requirements**
- **Structure of performance assessment**
- **Example uncertainty and sensitivity analysis results from performance assessment**

# Waste for Yucca Mountain



**Commercial Spent Nuclear Fuel:**  
**63,000 MTHM (~7500 waste packages)**



**DOE & Naval Spent Nuclear Fuel:**  
**2,333 MTHM**  
**(~400 naval waste packages)**  
**(DSNF packaged with HLW)**



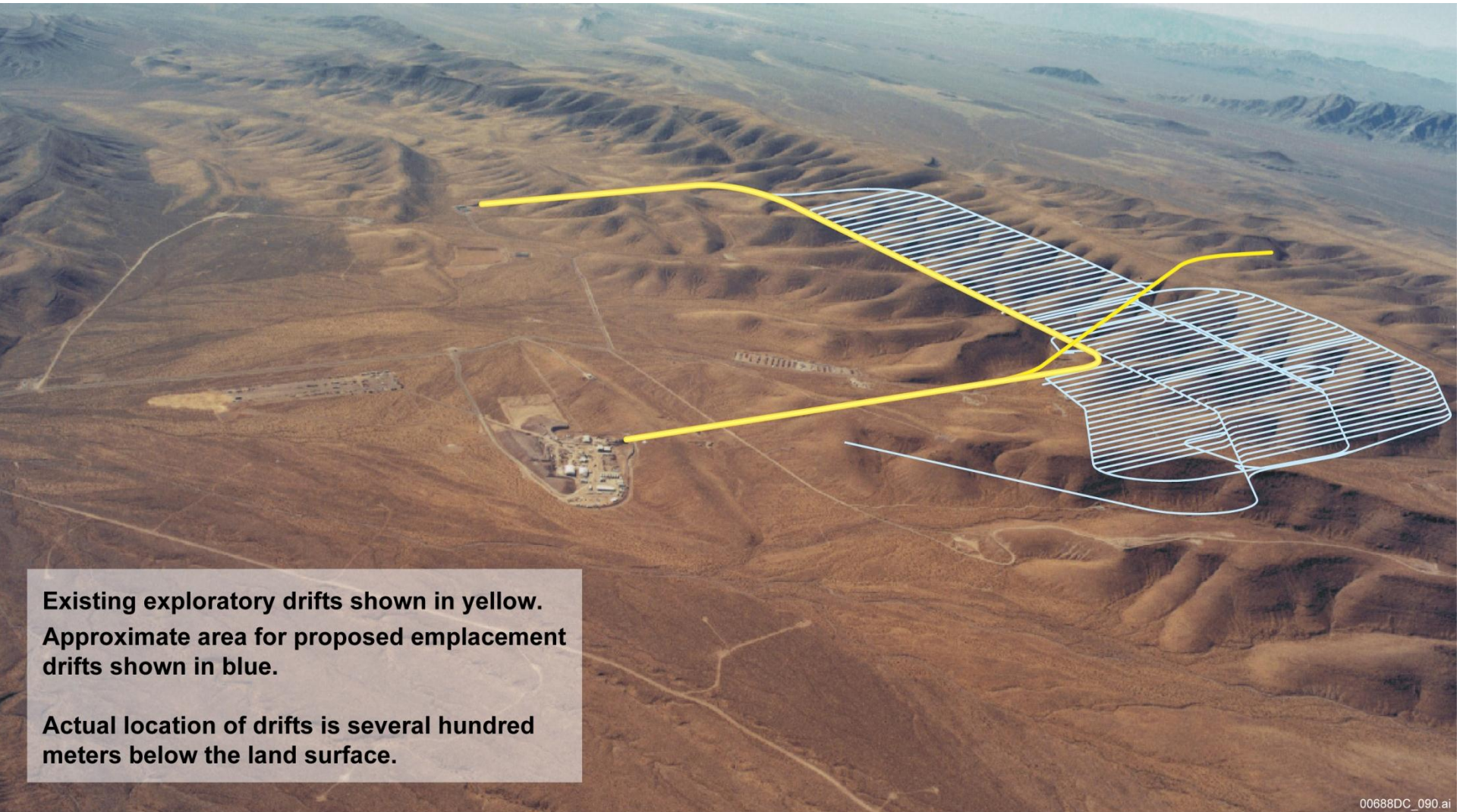
**DOE & Commercial High-Level Waste:**  
**4,667 MTHM**  
**(~3000 waste packages of co-disposed DSNF and HLW)**



DSNF: Defense Spent Nuclear Fuel  
HLW: High Level Radioactive Waste  
MTHM: Metric Tons Heavy Metal



# Proposed Repository for High-Level Waste and Spent Fuel at Yucca Mountain

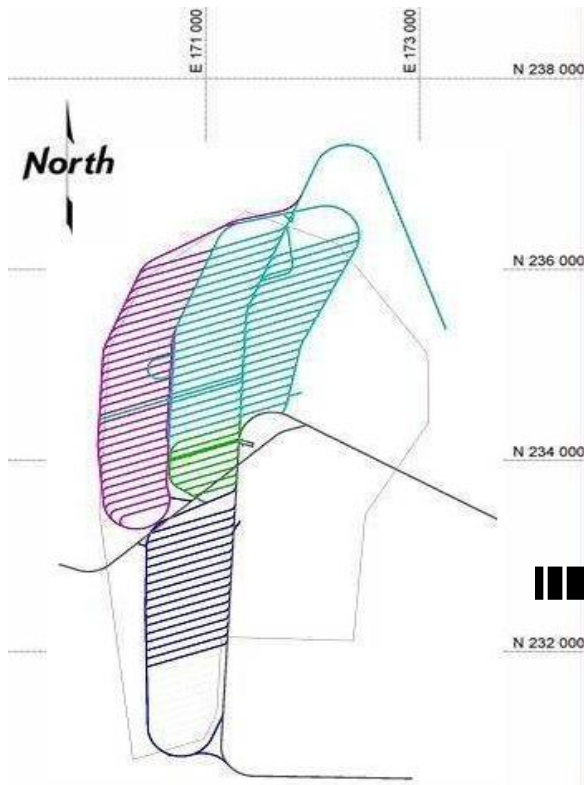


Existing exploratory drifts shown in yellow.  
Approximate area for proposed emplacement  
drifts shown in blue.

Actual location of drifts is several hundred  
meters below the land surface.

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# Yucca Mountain Subsurface Design



## Emplacement drifts

5.5 m diameter

approx. 100 drifts, 600-800 m long

## Waste packages

~11,000 packages

~ 5 m long, 2 m diameter

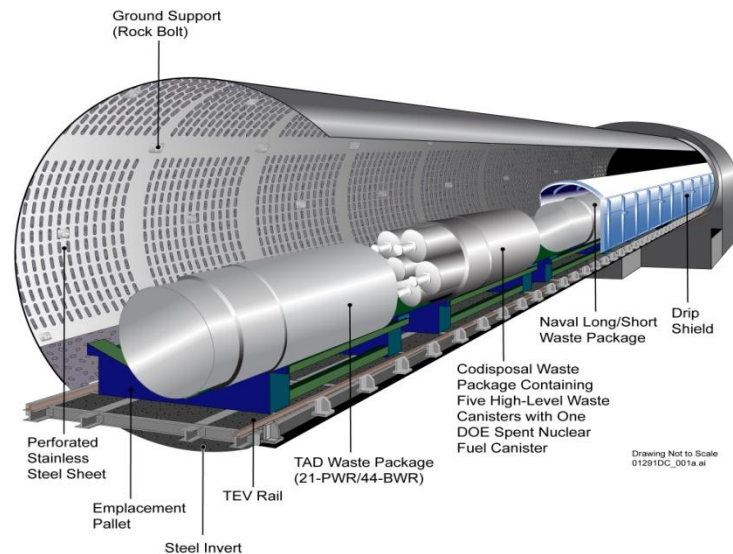
outer layer 2.5 cm Alloy 22 (Ni-Cr-Mo-V)

inner layer 5 cm stainless steel

Internal TAD (transportation, aging, and disposal) canisters  
for commercial spent fuel, 2.5 cm stainless steel

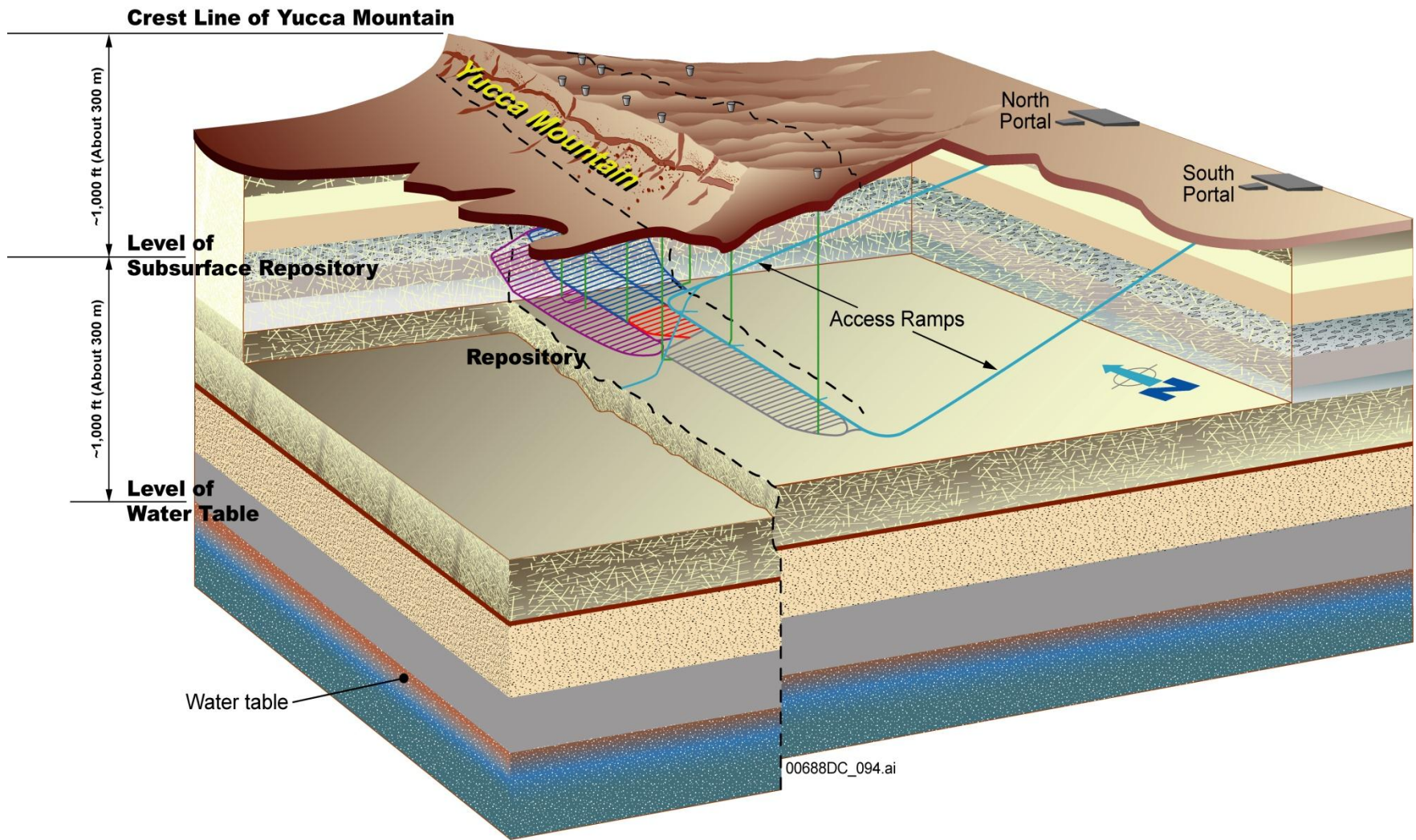
## Drip shields

free-standing 1.5 cm Ti shell





# Yucca Mountain Natural Features



# 10 CFR 63 and 40 CFR Part 197

## Core Regulatory Requirements for YM Repository

- **Maximum value of mean dose to the reasonably maximally exposed individual (RMEI) over time interval  $[0, 10^4 \text{ yr}]$  less than 15 mrem/yr**
- **Maximum value of mean dose to the RMEI over time interval  $[10^4, 10^6 \text{ yr}]$  less than 100 mrem/yr**
- **Take uncertainties and gaps in knowledge into account**
- **Requirements lead to Performance Assessment that**
  - **Computes measures of performance (e.g. mean dose)**
  - **Accounts for and quantifies uncertainty in measures of performance**

# Four Questions Underlying YM TSPA

## *(Yucca Mountain Total System Performance Assessment)*

➤ Q1: What can happen?

➤ Q2: How likely is it to happen?

➤ Q3: What are the consequences if it does happen?

➤ Q4: What is the uncertainty in the answers to the first three questions?

### ➤ *Guidance from YMRP*

**Risk-Informed Review Process for Performance Assessment**—The performance assessment quantifies repository performance, as a means of demonstrating compliance with the postclosure performance objectives at 10 CFR 63.113. The U.S. Department of Energy performance assessment is a systematic analysis that answers the triplet risk questions: what can happen; how likely is it to happen; and what are the consequences. (YMRP - *Yucca Mountain Review Plan*, p. 2.2-1)



# Uncertainty in YM TSPA

## Aleatory Uncertainty

- Inherent randomness in events that could occur in the future
- Alternative descriptors: irreducible, stochastic, intrinsic, type A
- Examples:
  - *Time and size of an igneous event*
  - *Time and size of a seismic event*

## Epistemic uncertainty

- Lack of knowledge about appropriate value to use for a quantity assumed to have a fixed value
- Alternative descriptors: reducible, subjective, state of knowledge, type B
- Examples:
  - *Spatially averaged permeabilities, porosities, sorption coefficients, ...*
  - *Rates defining Poisson processes*

# Example NRC Statements Related to Uncertainty in YM TSPA

## Aleatory Uncertainty

The Commission expects that performance assessments conducted by the applicant in support of any potential license application will use probabilistic methods to simulate a wide range of possible future behaviors of the repository system. Each possible future behavior of the repository system is represented by a curve describing the annual dose to the RMEI as a function of time. Generally, but not necessarily, each of the possible curves is assumed to be equally likely. Because none of these possible futures can be demonstrated to describe the actual future behavior of the repository system, the Commission requires that the applicant calculate the mean of these dose versus time curves, properly weighted by their individual probabilities. (10 CFR Parts 2,19,20, etc., p. 55813)

## Epistemic uncertainty

DOE is expected to conduct uncertainty analyses (i.e., evaluation of how uncertainty in parameter values affects uncertainty in the estimate of dose), including the consideration of disruptive events and associated probability of occurrence. (10 CFR Parts 2,19,20, etc., p. 55747)

The approach defined in part 63, which requires DOE to fully address uncertainties in its performance assessment rather than requiring DOE to meet a specific level of uncertainty, is appropriate. The treatment of uncertainty in DOE's performance assessment will be an important part of NRC's review. (10 CFR Parts 2,19,20, etc., p. 55748)

# Basic Entities Underlying YM TSPA

## EN1: Probabilistic characterization of what can happen in the future

- Answers first two questions
- Provides formal characterization of aleatory uncertainty

*E.G. Assumption that igneous event occurrence is a Poisson process*

## EN2: Mathematical models for predicting consequences

- Answers third question

*E.G. Models implemented in Goldsim*

## EN3: Probabilistic characterization of uncertainty in TSPA inputs

- Basis for answering fourth question
- Provides formal characterization of epistemic uncertainty

*E.G. Distribution assigned to  $\lambda$  in Poisson process for igneous event*

# Basic Entities Underlying YM TSPA

## EN1: Probabilistic characterization of what can happen in the future

Aleatory  
uncertainty

- $\mathbf{a} = [a_1, a_2, \dots]$  vector characterizing a possible future at YM site
  - E.G.  $\mathbf{a} = [nSG, t_1, v_1, t_2, v_2, \dots, t_{nSG}, v_{nSG}]$  for seismic ground motion events in time interval  $[0, 10^4 \text{ yr}]$ , where  $nSG$  = number of seismic events,  $t_i$  = time (yr) of  $i^{\text{th}}$  event, and  $v_i$  = PGV for  $i^{\text{th}}$  event
- $\mathcal{A}$  = set of all possible values for  $\mathbf{a}$
- Formally, a probability space  $(\mathcal{A}, \mathcal{A}, p_A)$  with density function  $d_A(\mathbf{a})$

TSPA AMR,

Sect J4.4

## EN3: Probabilistic characterization of uncertainty in TSPA inputs

Epistemic  
uncertainty

- $\mathbf{e} = [\mathbf{e}_A, \mathbf{e}_M] = [e_1, e_2, \dots, e_{nE}]$  vector of uncertainty in TSPA inputs
  - $\mathbf{e}_A$  vector of uncertain inputs used in characterizing aleatory uncertainty
  - $\mathbf{e}_M$  vector of uncertain model inputs used in calculating consequences
- $\mathcal{E}$  = set of all possible values for  $\mathbf{e}$
- Formally, a probability space  $(\mathcal{E}, \mathcal{E}, p_E)$  with density function  $d_E(\mathbf{e})$

TSPA AMR,

Tables K3-1, K3-2, K3-3

## EN2: Mathematical models for predicting consequences

- Sequence of complex linked models
  - E.G.  $D(\tau | \mathbf{a}, \mathbf{e}_M)$  = dose to RMEI (mrem/yr) at time  $\tau$  for future  $\mathbf{a}$  and conditional on parameter values in  $\mathbf{e}_M$

TSPA AMR, Chapter 6



# EN1: Probability Space For Aleatory Uncertainty

- Defining vector for individual future **a** (Eq. J4.4-1)

$$\mathbf{a} = [nEW, nED, nII, nIE, nSG, nSF, \mathbf{a}_{EW}, \mathbf{a}_{ED}, \mathbf{a}_{II}, \mathbf{a}_{IE}, \mathbf{a}_{SG}, \mathbf{a}_{SF}]$$

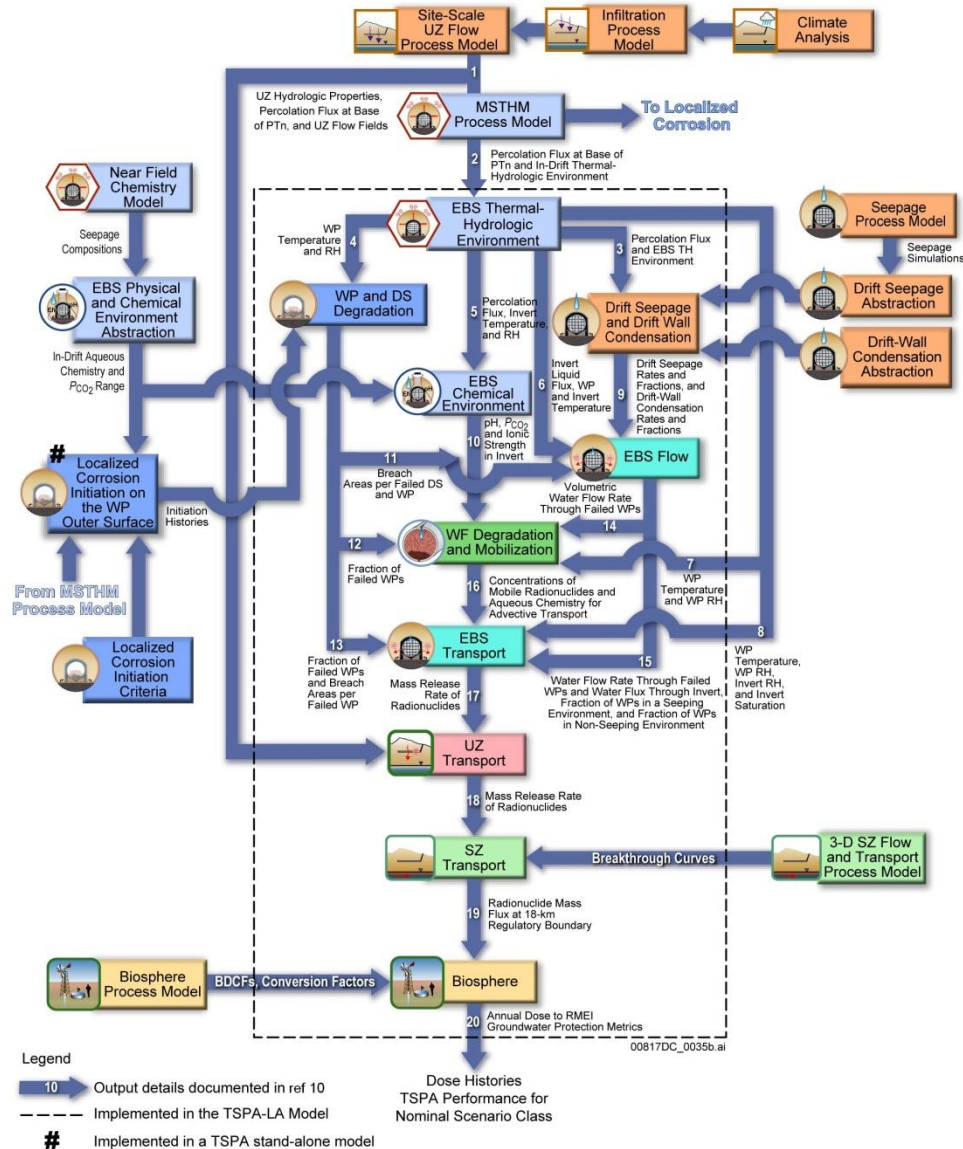
where, for the time interval  $[0, 2 \times 10^4 \text{ yrs}]$  or  $[0, 10^6 \text{ yrs}]$

- $nEW$  = number of early WP failures
- $nED$  = number of early DS failures
- $nII$  = number of igneous intrusive events
- $nIE$  = number of igneous eruptive events
- $nSG$  = number of seismic ground motion events
- $nSF$  = number of fault displacement events
- $\mathbf{a}_{EW}$  = vector defining  $nEW$  early WP failures (Eqs. J6.1-12, J6.2-1)
- $\mathbf{a}_{ED}$  = vector defining  $nED$  early DS failures (Eqs. J6.1-13, J6.3-1)
- $\mathbf{a}_{II}$  = vector defining  $nII$  igneous intrusive events (Eqs. J7.1-8, J7.2-1)
- $\mathbf{a}_{IE}$  = vector defining  $nIE$  igneous eruptive events (Eqs. J7.1-9, J7.3-1)
- $\mathbf{a}_{SG}$  = vector defining  $nSG$  seismic ground motion events (Eqs. J8.1-8, J8.2-1, J8.3-1)
- $\mathbf{a}_{SF}$  = vector defining  $nSF$  fault displacement events (Eqs. J8.1-9, J8.6-1)

- Set  $\mathcal{A}$  of all futures (Eq. J4.4-2)

$$\mathcal{A} = \{\mathbf{a} : \mathbf{a} = [nEW, nED, nII, nIE, nSG, nSF, \mathbf{a}_{EW}, \mathbf{a}_{ED}, \mathbf{a}_{II}, \mathbf{a}_{IE}, \mathbf{a}_{SG}, \mathbf{a}_{SF}]\}$$

# EN2: Models for Nominal Scenario Class



# EN3: Probability Space for Epistemic Uncertainty

- 392 epistemically uncertain analysis inputs
- $\mathbf{e} = [e_1, e_2, \dots, e_{392}]$
- Example elements of  $\mathbf{e}$

*ASHDENS* - Tephra settled density ( $\text{kg/m}^3$ ). *Distribution*: Truncated normal.. *Range*: 300 to 1500. *Mean*: 1000. *Standard Deviation*: 100.

*IGRATE* - Frequency of intersection of the repository footprint by a volcanic event ( $\text{yr}^{-1}$ ). *Distribution*: Piecewise uniform. *Range*: 0 to  $7.76\text{E}-07$ .

*INFIL* - Pointer variable for determining infiltration conditions: 10<sup>th</sup>, 30<sup>th</sup>, 50<sup>th</sup> or 90<sup>th</sup> percentile infiltration scenario (dimensionless). *Distribution*: Discrete. *Range*: 1 to 4.

*MICPU239* - Groundwater biosphere dose conversion factor (BDCF) for  $^{239}\text{Pu}$  in modern interglacial climate ( $(\text{Sv/year})/(\text{Bq/m}^3)$ ). *Distribution*: Discrete. *Range*:  $3.49\text{E}-07$  to  $2.93\text{E}-06$ . *Mean*:  $9.55\text{E}-07$ .

*SZFISPVO* - Flowing interval spacing in fractured volcanic units (m). *Distribution*: Piecewise uniform. *Range*: 1.86 to 80.

# Computational Strategy

- **Maintain separation of aleatory and epistemic uncertainty**
  - Epistemic uncertainty in expected dose and other quantities
  - Informative sensitivity analyses
- **Procedures for uncertainty propagation**
  - Sampling-based (LHS) for epistemic uncertainty
  - Integration-based for aleatory uncertainty
- **Seek computational efficiencies in calculation of expected dose**
  - Linearities
  - Interpolations
  - Efficient use of computationally expensive results
- **Produce three types of results for presentation and/or sensitivity analysis**
  - Distributions and expected values over epistemic uncertainty conditional on a specific realization of aleatory uncertainty
  - Distributions and expected values over aleatory uncertainty conditional on a specific realization of epistemic uncertainty
  - Expected values over both aleatory and epistemic uncertainty



# Computational Strategy (cont.)

- **Perform extensive sensitivity analysis**

- Investigation of sampling-based mapping between uncertain TSPA inputs and TSPA results
- Multiple locations: WP, EBS, UZ, SZ, RMEI
- Multiple time-dependent and spatially-dependent results: Solubilities, ionic strength, pH, temperature, release rates, integrated releases, dose
- Multiple radionuclides
- Multiple scenarios: nominal, early WP failure, early DS failure, igneous intrusive, igneous eruptive, seismic ground motion, seismic Fault displacement
- Multiple potential sensitivity analysis procedures
  - Examination of scatterplots and cobweb plots
  - Correlation and partial correlation analysis
  - Regression analysis
  - Stepwise regression analysis
  - Rank transforms to linearize monotonic relationships
  - Nonparametric regression: Loess, additive models, projection pursuit, recursive partitioning
  - Tests for patterns based on gridding: nonmonotonic relations, nonlinear relations
  - Tests for patterns based on distance measures
  - Multidimensional Kolmogorov-Smirnov test
  - Tree-based searches
  - Squared differences of ranks
  - Top-down concordance with replicated samples
  - Variance decomposition

- **Employ sensitivity analysis as part of analysis verification**

# Expected Dose

- **Formal representation**

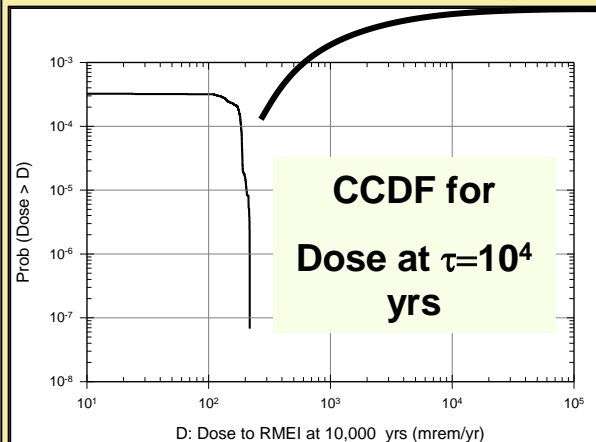
$$\bar{D}(\tau | \mathbf{e}_M) = E_A[D(\tau | \mathbf{a}, \mathbf{e}_M) | \mathbf{e}_A] = \int_{\mathcal{A}} D(\tau | \mathbf{a}, \mathbf{e}_M) d_A(\mathbf{a} | \mathbf{e}_A) d\mathbf{a}, \quad \mathbf{e} = [\mathbf{e}_A, \mathbf{e}_M]$$

- **Approximation**

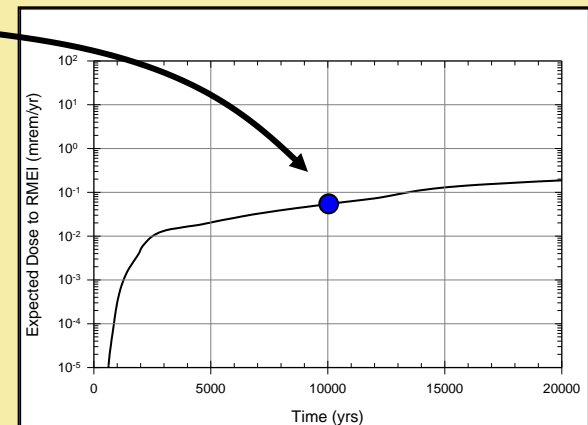
$$E_A[D(\tau | \mathbf{a}, \mathbf{e}_M) | \mathbf{e}_A] \cong \begin{cases} \sum_{i=1}^n D(\tau | \mathbf{a}_i, \mathbf{e}_M) / n & \text{Monte Carlo: } \mathbf{a}_i \text{'s sampled from } \mathcal{A} \text{ consistent} \\ & \text{with } d_A(\mathbf{a} | \mathbf{e}_A) \\ \sum_{i=1}^n D(\tau | \mathbf{a}_i, \mathbf{e}_M) p_A(\mathcal{A}_i | \mathbf{e}_A) & \text{Quadrature: } \mathcal{A} = \cup \mathcal{A}_i, \mathcal{A}_i \cap \mathcal{A}_j = \emptyset \\ & p_A(\mathcal{A}_i | \mathbf{e}_A) = \text{probability for } \mathcal{A}_i \\ & \text{consistent with } d_A(\mathbf{a} | \mathbf{e}_A) \end{cases}$$

Ordered triplet:  $\{ [\mathcal{A}_i, p_A(\mathcal{A}_i | \mathbf{e}_A), D(\tau | \mathbf{a}_i, \mathbf{e}_M)], i = 1, 2, \dots, n \}$

- **Graphical representation (Ex: Igneous intrusion)**



$$E_A[D(10^4 | \mathbf{a}, \mathbf{e}_M) | \mathbf{e}_A]$$



# Uncertainty in Expected Dose over Aleatory Uncertainty

- Different value for

$$E_A[D(\tau | \mathbf{a}, \mathbf{e}_M) | \mathbf{e}_A] = \int_{\mathcal{A}} D(\tau | \mathbf{a}, \mathbf{e}_M) d_A(\mathbf{a} | \mathbf{e}_A) d\mathbf{a}$$

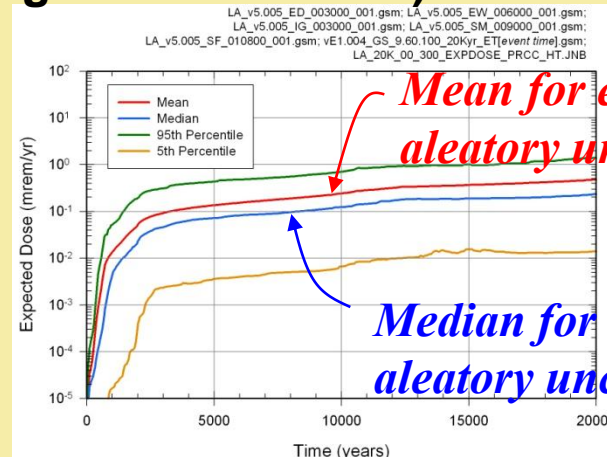
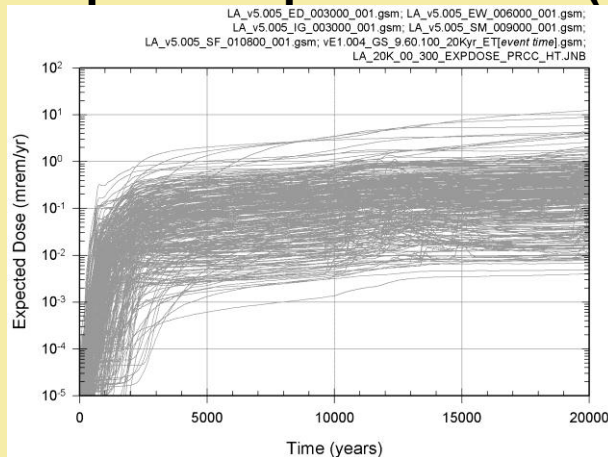
for each  $\mathbf{e} = [\mathbf{e}_A, \mathbf{e}_M]$

- Approximation to uncertainty in  $E_A[D(\tau | \mathbf{a}, \mathbf{e}_M) | \mathbf{e}_A]$

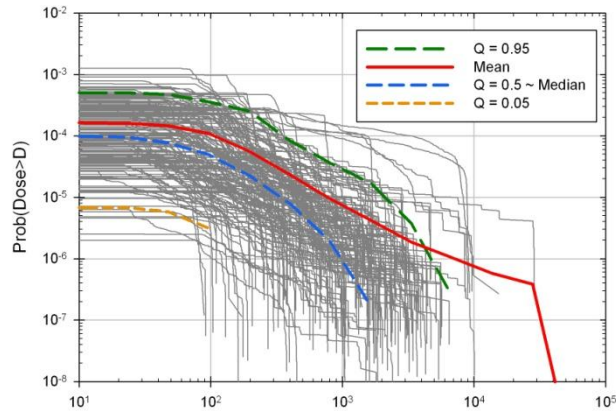
$$E_A[D(\tau | \mathbf{a}, \mathbf{e}_{Mj}) | \mathbf{e}_{Aj}], \quad j = 1, 2, \dots, n$$

for LHS  $\mathbf{e}_1, \mathbf{e}_2, \dots, \mathbf{e}_n$  from  $\mathcal{E}$  consistent with  $d_E(\mathbf{e})$


- Graphical representation (Ex: Igneous intrusion)

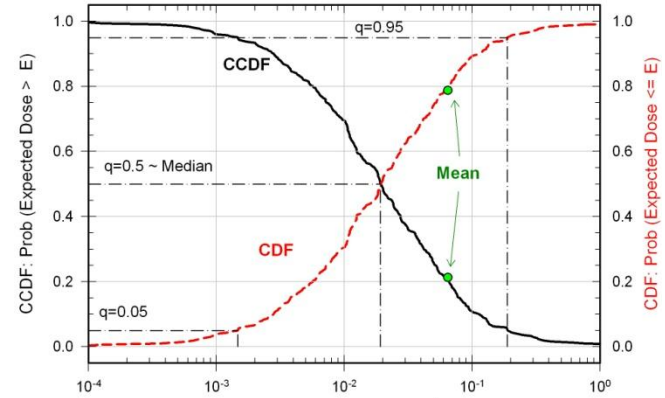


# Progression from Dose to Mean Dose



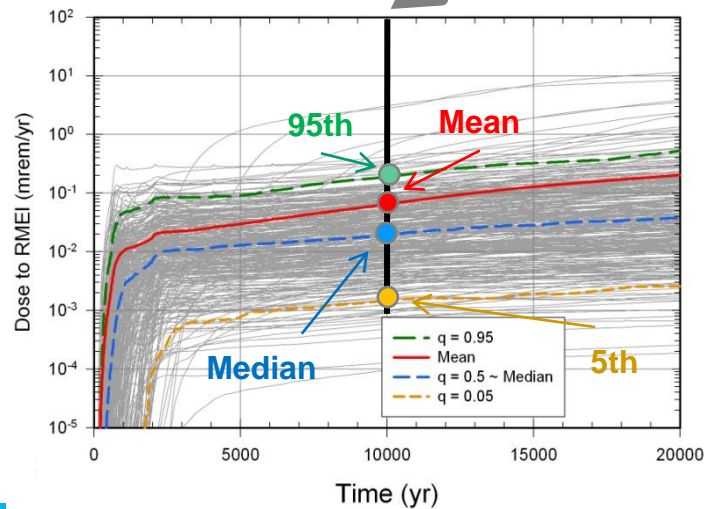
D: Dose to RMEI at 10,000 yr (mrem/yr)

**Expected Dose**  
  
**at  $10^4$  yr**



E: Expected Dose to RMEI at  $10^4$  yr (mrem/yr)

**Summary**  
**at  $10^4$  yr**





# Decomposition of Expected Dose $\bar{D}(\tau | e)$ Conditional on $e=[e_A, e_M]$

$$\begin{aligned}
 \bar{D}(\tau | e) &= E_A[D(\tau | \mathbf{a}, \mathbf{e}_M) | \mathbf{e}_A] \\
 &= \int_{\mathcal{A}} D(\tau | \mathbf{a}, \mathbf{e}_M) d_A(\mathbf{a} | \mathbf{e}_A) d\mathbf{a} \quad (\text{Conservation of probability}) \\
 &\cong \int_{\mathcal{A}} \sum_{S \in \mathcal{S}} D_S(\tau | \mathbf{a}, \mathbf{e}_M) d_A(\mathbf{a} | \mathbf{e}_A) d\mathbf{a}, \quad \mathcal{S} = \{N, EW, ED, II, IE, SG, SF\} \\
 &\quad (\text{No significant synergisms approximation}) \\
 &= \sum_{S \in \mathcal{S}} \int_{\mathcal{A}_S} D_S(\tau | \mathbf{a}, \mathbf{e}_M) d_A(\mathbf{a} | \mathbf{e}_A) d\mathbf{a} \\
 &= D_N(\tau | \mathbf{e}_M) + \bar{D}_{EW}(\tau | e) + \bar{D}_{ED}(\tau | e) + \bar{D}_{II}(\tau | e) + \bar{D}_{IE}(\tau | e) + \bar{D}_{SG}(\tau | e) + \bar{D}_{SF}(\tau | e)
 \end{aligned}$$

where

- $D_S(\tau | \mathbf{a}, \mathbf{e}_M)$  ~ dose (mrem/yr) at time  $\tau$  from part of  $\mathbf{a}$  corresponding to event  $S$
- $\mathcal{A}_S$  ~ subset of  $\mathcal{A}$  in which event  $S$  occurs
- $N$  ~ nominal conditions ..... Nominal scenario class
- $EW$  ~ early WP failure events •  $ED$  ~ early DS failure events ..... Early failure scenario class
- $II$  ~ igneous intrusive events •  $IE$  ~ igneous eruptive events ..... Igneous scenario class
- $SG$  ~ seismic ground motion events •  $SF$  ~ fault displacement events ..... Seismic scenario class

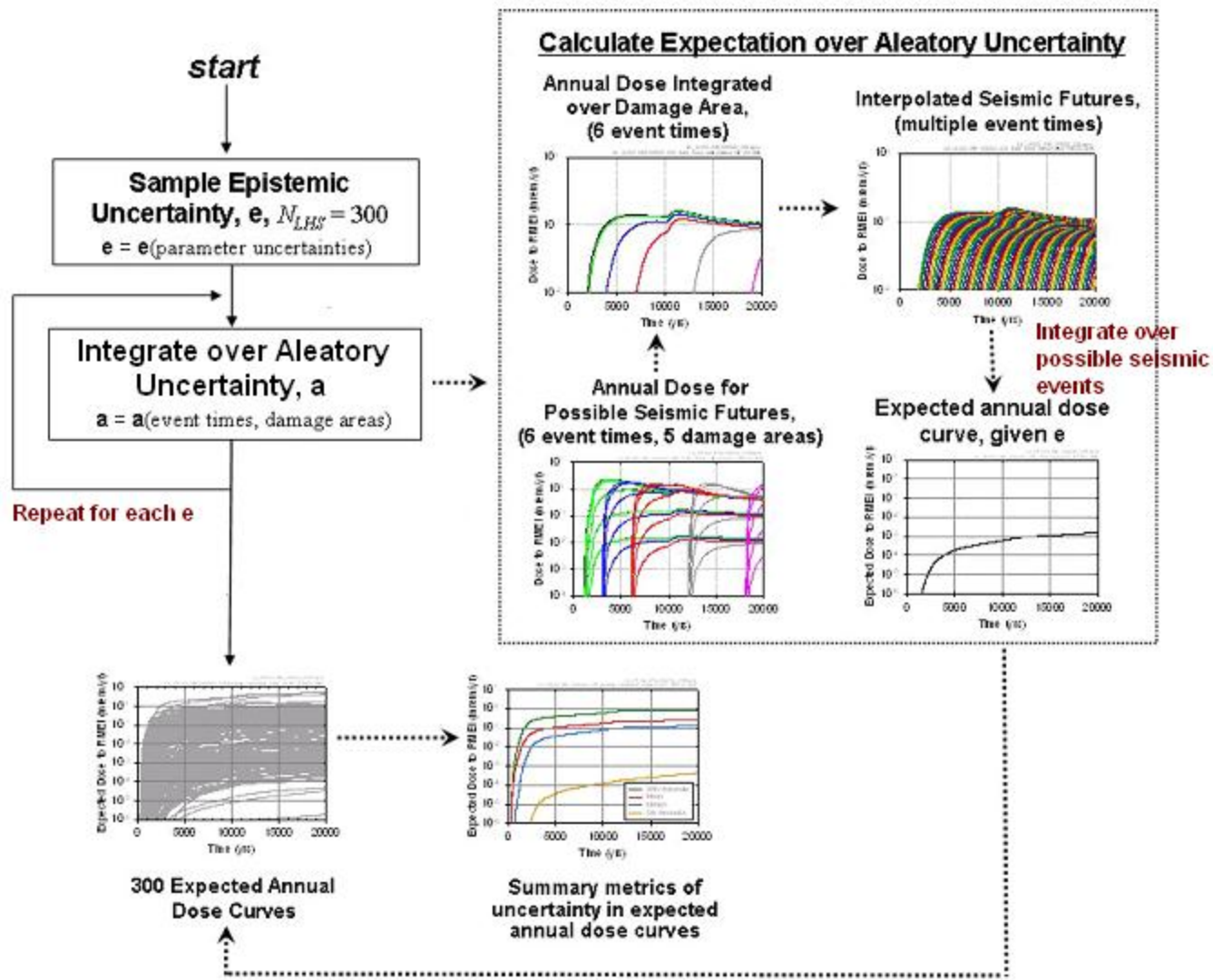
*TSPA AMR, Sect J4.6-J4.8*

# Evaluation of $\bar{D}_S(\tau | \mathbf{e}) = \int_{\mathcal{A}_S} D_S(\tau | \mathbf{a}, \mathbf{e}_M) d_A(\mathbf{a} | \mathbf{e}_A) dA$

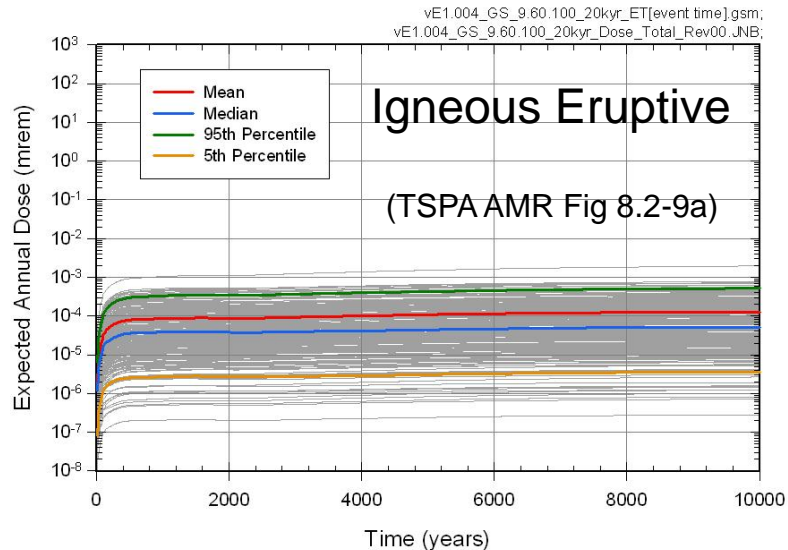
for  $S = \{N, EW, ED, II, IE, SG, SF\}$

- $N \sim$  nominal conditions *TSPA AMR, Sect. J5*
  - Always zero for  $[0, 2 \times 10^4 \text{ yrs}]$
  - Combined with seismic ground motion (SG) for  $[0, 10^6 \text{ yrs}]$
- $EW, ED \sim$  early WP and DS failures *TSPA AMR, Sect. J6*
  - Summation of probabilistically weighted results for individual failures
- $II \sim$  igneous intrusive events *TSPA AMR, Sect. J7*
  - Quadrature procedure
- $IE \sim$  igneous eruptive events *TSPA AMR, Sect. J7*
  - Combined quadrature/Monte Carlo procedure
- $SG \sim$  seismic ground motion events *TSPA AMR, Sect. J8*
  - Quadrature procedure for  $[0, 2 \times 10^4 \text{ yrs}]$
  - Monte Carlo procedure for  $[0, 10^6 \text{ yrs}]$
- $SF \sim$  fault displacement events *TSPA AMR, Sect. J8*
  - Quadrature procedure

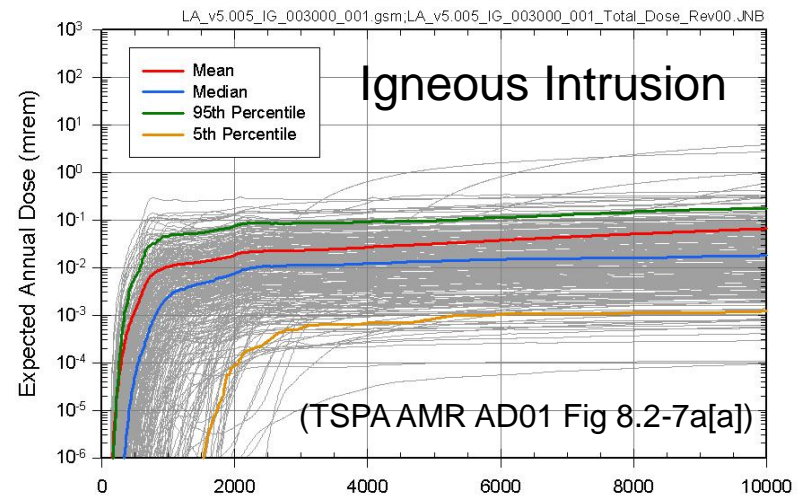
# Calculation of Expected Dose (seismic GM)



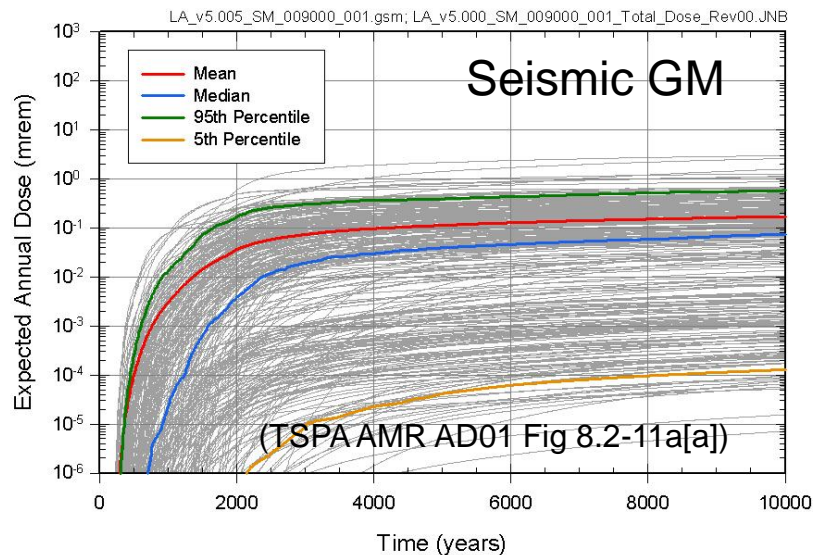
# Total Expected Dose



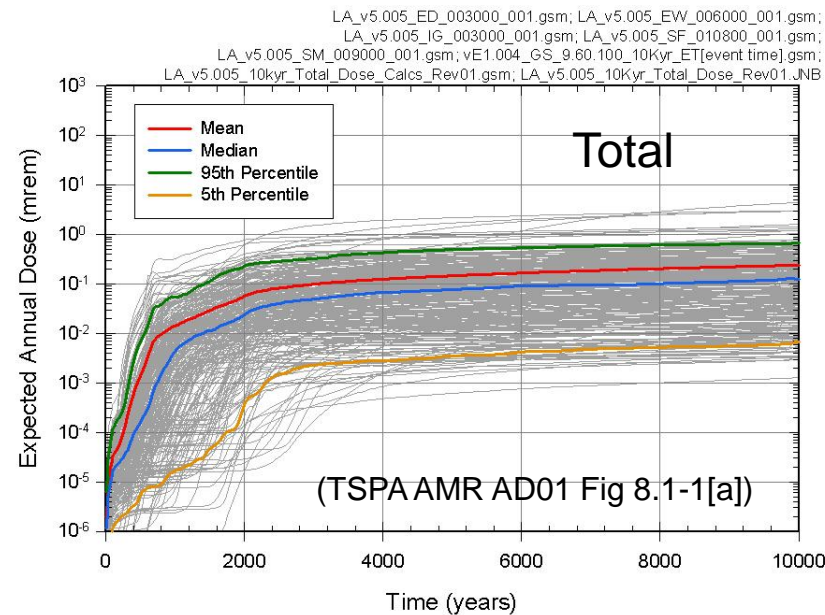
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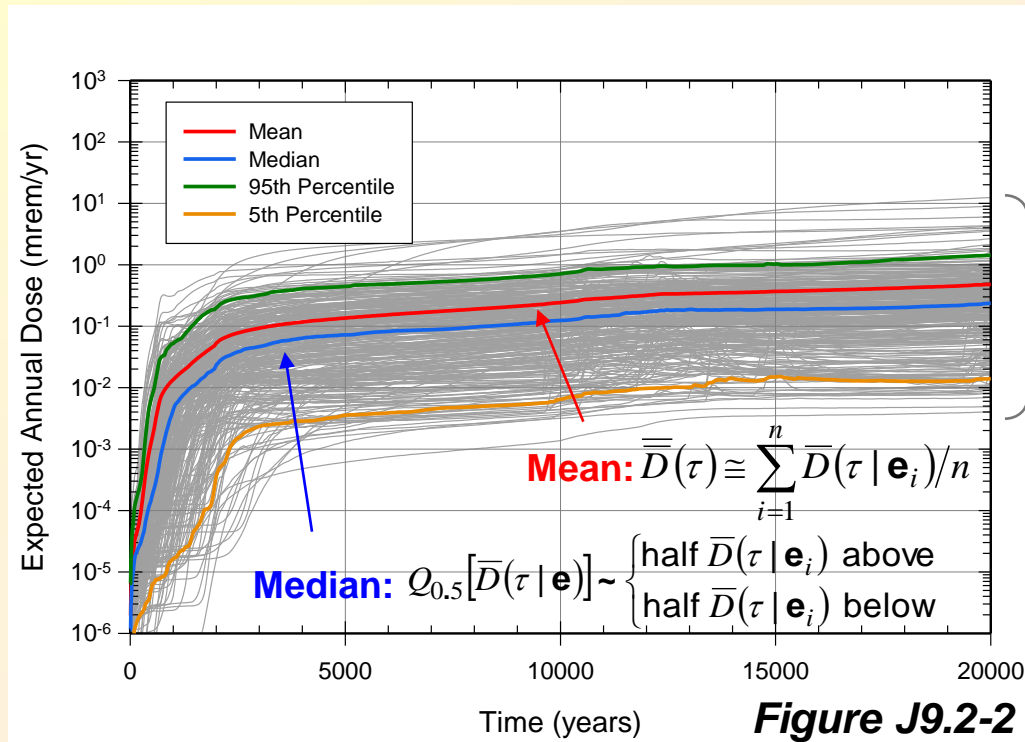
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# Epistemic Uncertainty in Expected Dose $\bar{D}(\tau | \mathbf{e})$

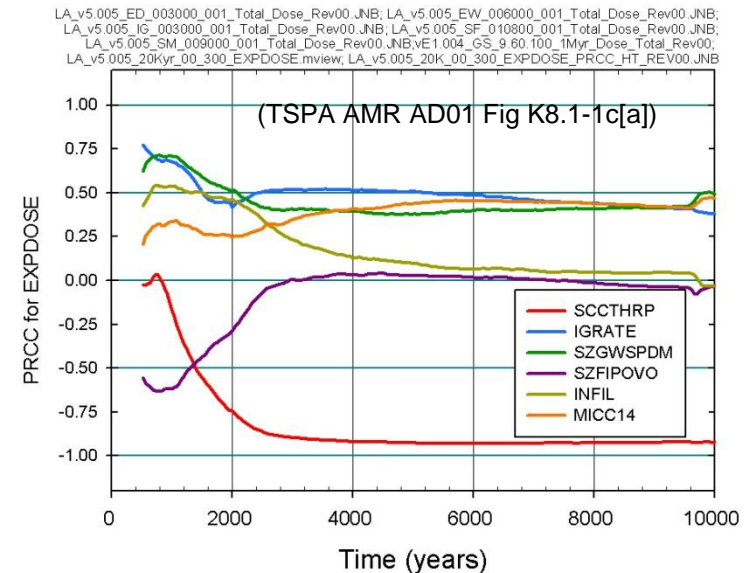
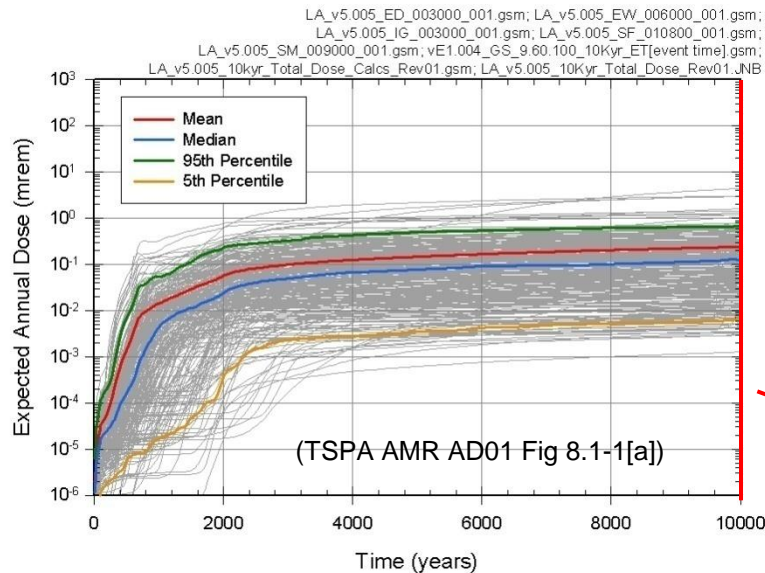
- Derives from probability space  $(\mathcal{E}, \mathcal{E}, p_{\mathcal{E}})$  ( TSPA AMR, Sect. J3.5, Tables K3-1, K3-2, K3-3 )
- Assess with LHS  $\mathbf{e}_i$ ,  $i=1,2,\dots,n$ , from  $\mathcal{E}$  ( TSPA AMR, Sect. J3.5, J4.9, J4.10 )



- Perform sensitivity analysis on mapping  $[\mathbf{e}_i, \bar{D}(\tau | \mathbf{e}_i), D_N(\tau | \mathbf{e}_i), \bar{D}_{EW}(\tau | \mathbf{e}_i), \dots]$ ,  $i = 1, 2, \dots, n$

( TSPA AMR, App. K )

# Uncertainty in Total Expected Dose



**SCCTHRP – stress threshold for SCC initiation (90 to 105% of yield strength)**

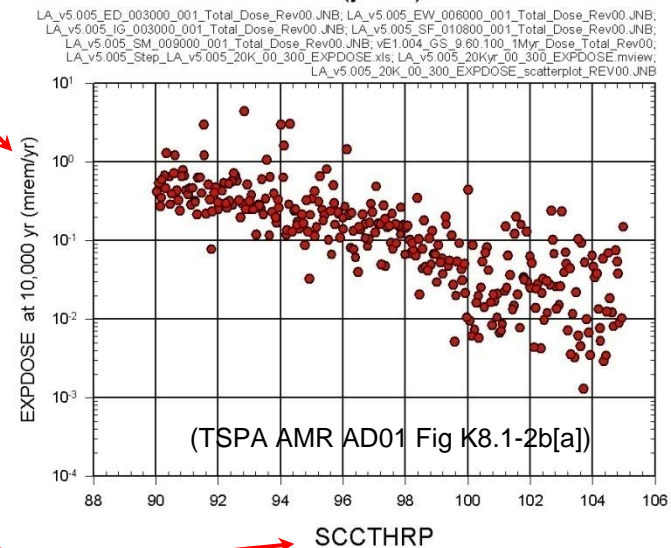
IGRATE – frequency of igneous events

SZGWSPDM – logarithm of uncertainty factor in groundwater specific discharge

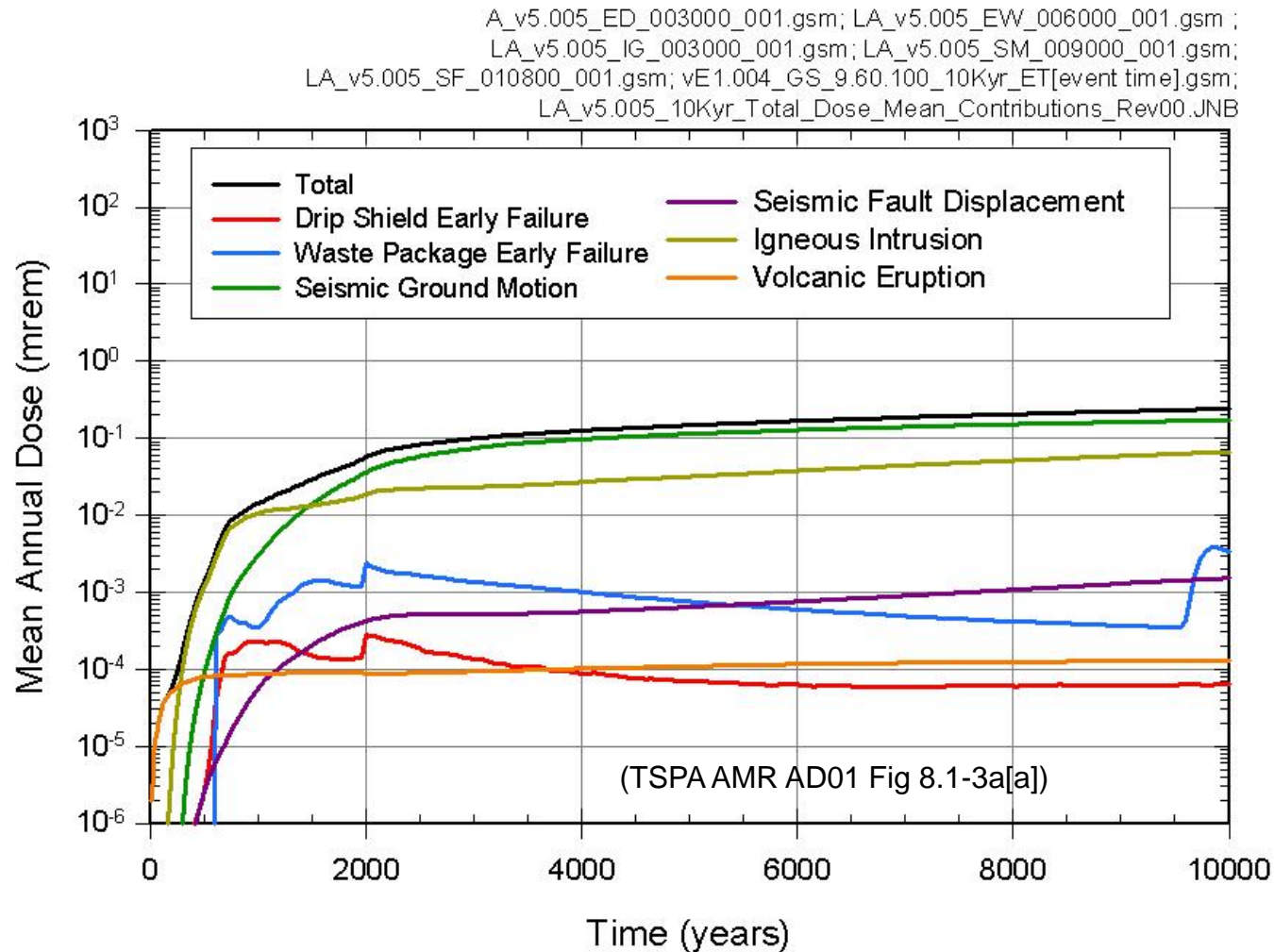
SZFIPOVO – flowing interval porosity in volcanic units

INFIL – infiltration case

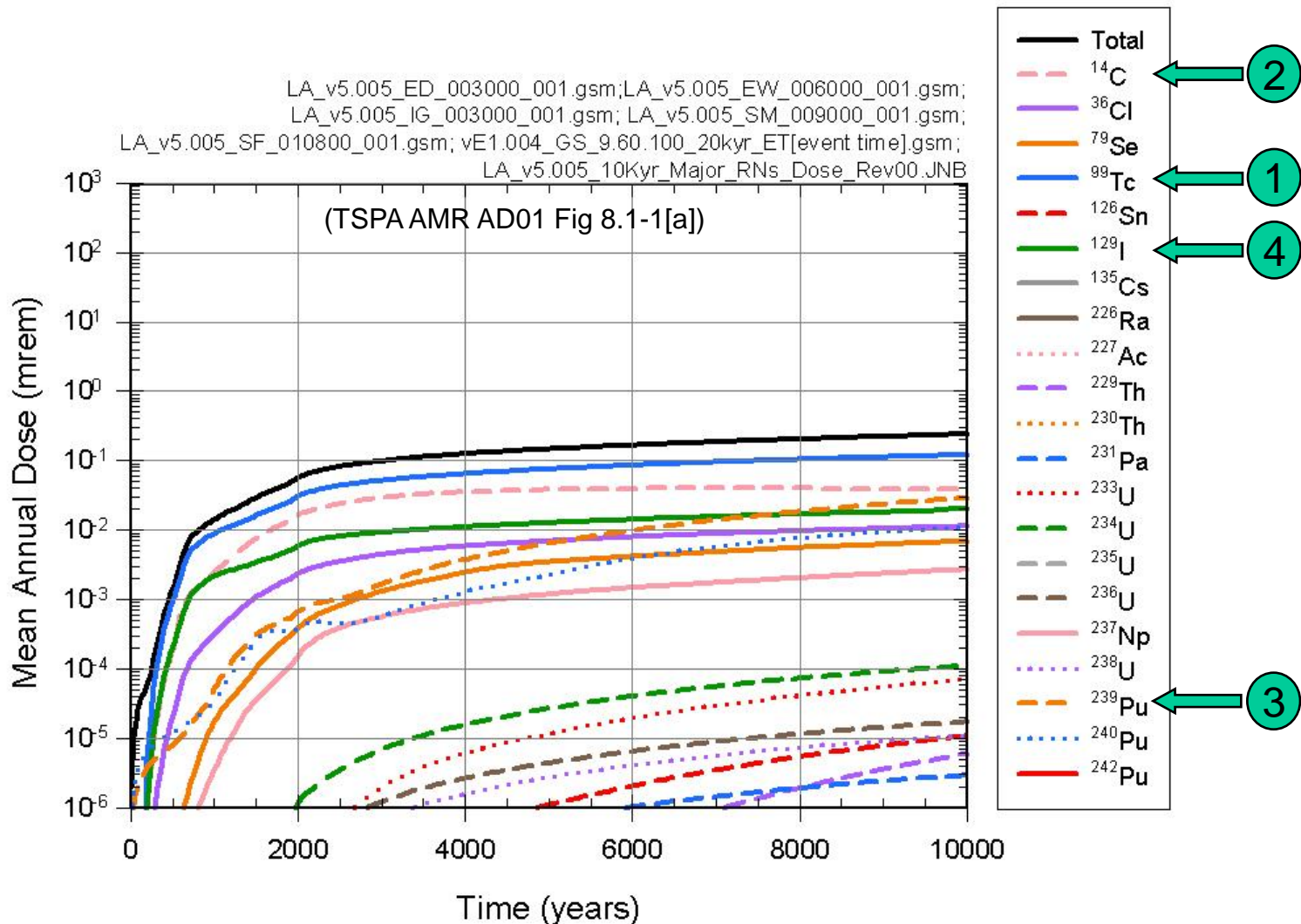
MICC14 – biosphere dose conversion factor for C14



# Total Mean Dose Contributions By Modeling Case

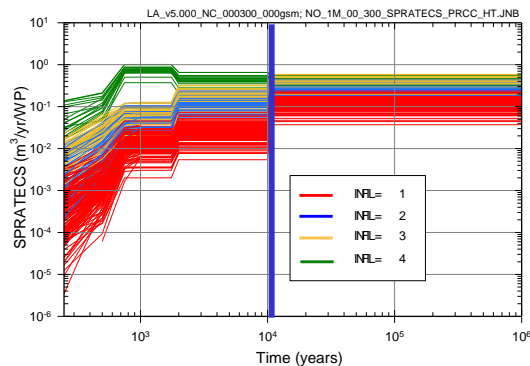


# Radionuclides Contributing to Total Mean Dose at 10,000 Years

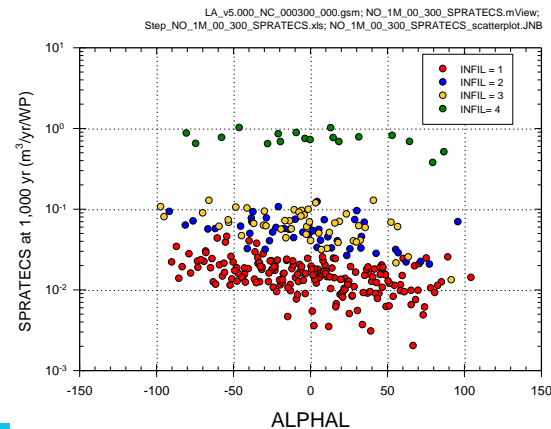
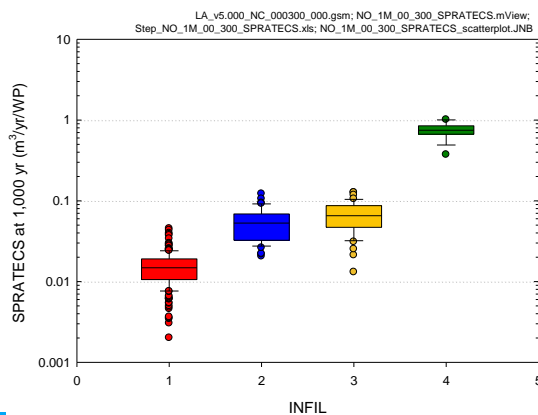


# Uncertain Model for Infiltration

- **INFIL** – Pointer variable for four alternative surface infiltration models
- Results in four alternative three dimensional flow fields
- Many effects including: seepage rates ( $\text{m}^3/\text{yr}/\text{WP}$ ) above CSNF WPs in percolation bin 3 under nominal conditions (TSPA AMR Figs K4.3-1, -2)

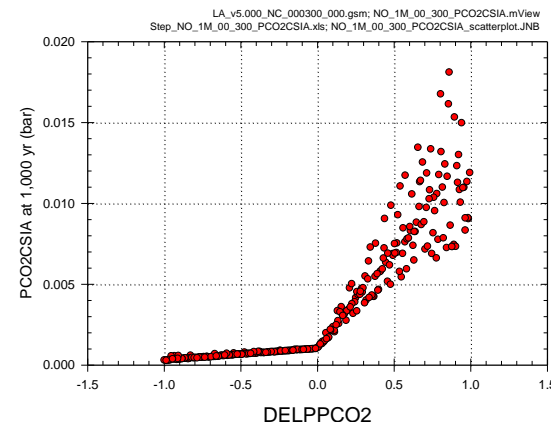
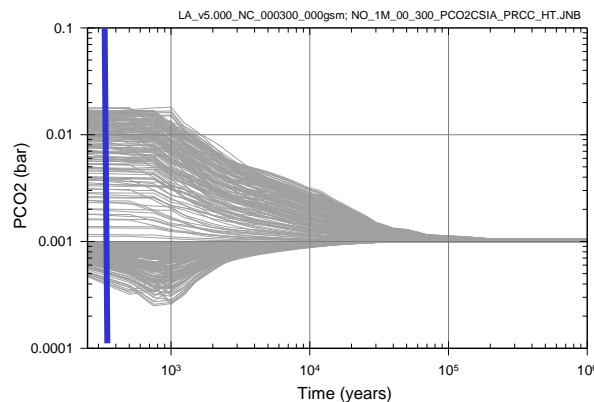


SPRATECS: 1K yr			
Step	Variable	R <sup>2</sup>	SRRC <sup>d</sup>
1	INFIL	0.67	0.83
2	SEEPFRMN	0.76	-0.28
3	ALPHAL	0.82	-0.26
4	SEEPFRM	0.85	-0.19
5	SEEPUNC	0.87	0.15
6	INFRCTC	0.88	0.06
7	CORRATSS	0.88	-0.05



# Uncertain Model for CO<sub>2</sub> Partial Pressure

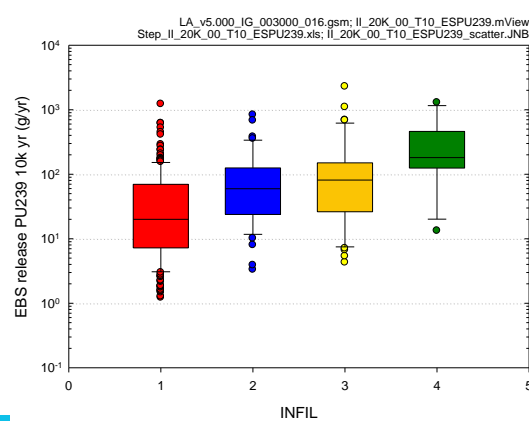
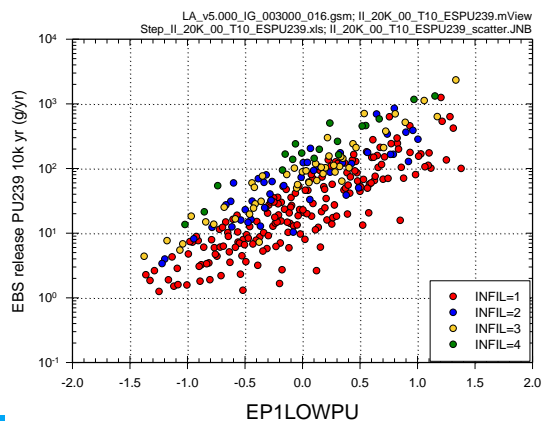
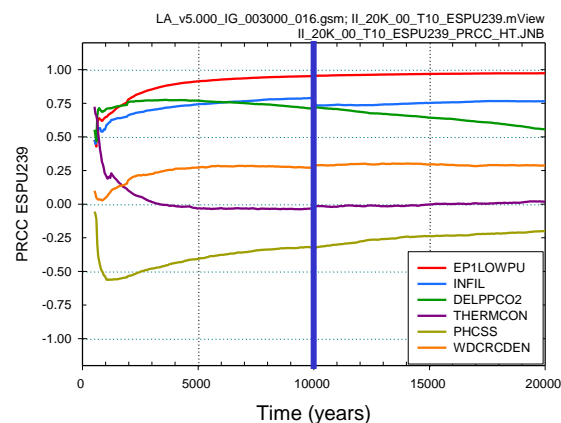
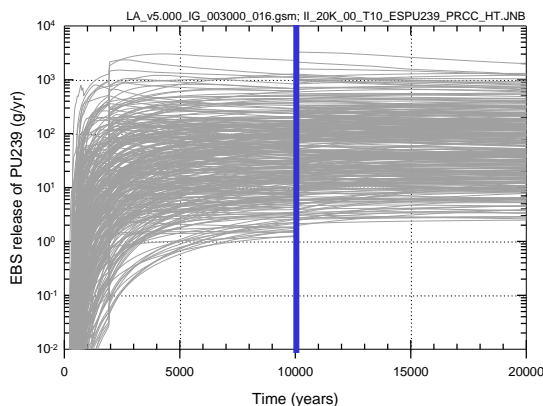
- **DELPPCO2** – Selector variable for CO<sub>2</sub> Partial Pressure model
  - Uniform on [-1,1], with negative and positive values indicating Mode 1 or 2, respectively
  - |DELPPCO2| scales model results
- Example results: Partial pressure for CO<sub>2</sub> (bars) in invert for CSNF WPs experiencing dripping conditions in percolation bin 3 under nominal conditions (TSPA AMR Figs. K.4.3-7,-8)





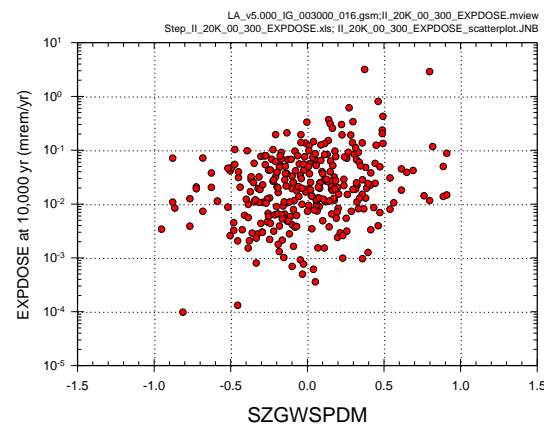
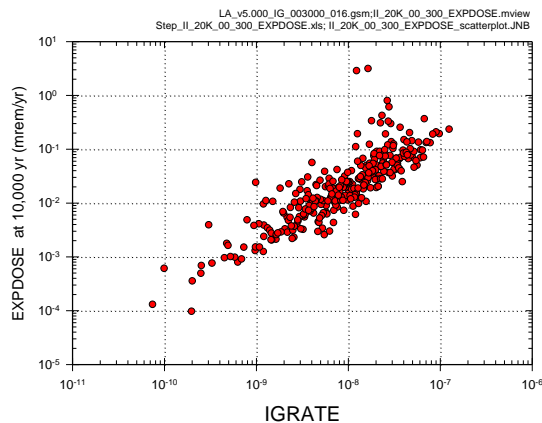
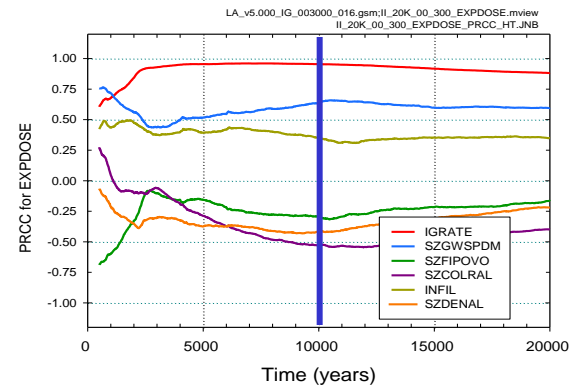
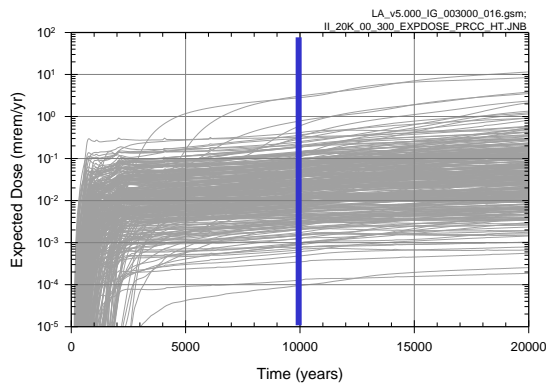
# Uncertain Model for Plutonium Solubility

- **EP1LOWPU** – Logarithm of scale factor for plutonium solubility model under low ionic strength conditions. Distribution: truncated normal on  $[-1.4, 1.4]$  with  $\mu=0.0$  ;  $\sigma=0.7$
- Example results: Release rate (g/yr) of dissolved  $^{239}\text{Pu}$  from EBS for igneous event at 10 yr that destroys all WPs (TSPA AMR Figs K6.3.1-7,-8)



# Uncertain Model for Poisson Process

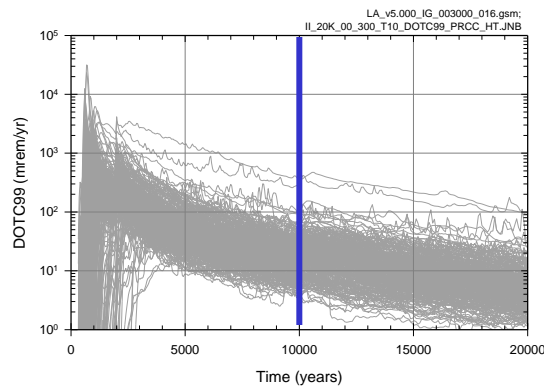
- **IGRATE** – Defining rate ( $\text{yr}^{-1}$ ) for Poisson model for occurrence of igneous events. Piecewise uniform on  $[0, 7.76 \times 10^{-7} \text{ yr}^{-1}]$
- Example: Expected dose (mrem/yr) to RMEI from igneous intrusion (TSPA AMR Figs K6.7.1-1,-2)



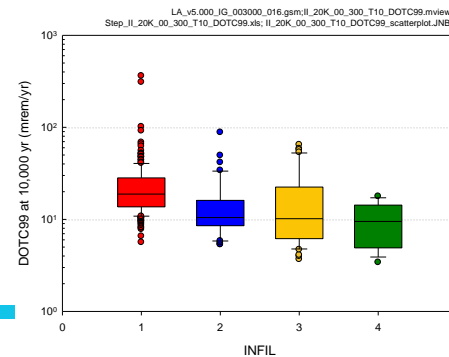
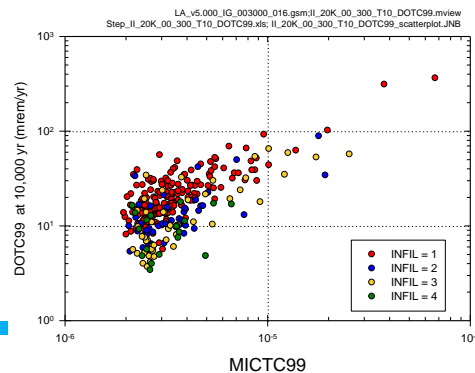
**More interesting: Uncertain hazard curves**

# Uncertain Model for Dose Conversion

- **MICTC99** – Groundwater dose conversion factor ((Sv/yr)/(Bq/l)) for  $^{99}\text{Tc}$ . Discrete from  $[5.28 \times 10^{-6}, 2.85 \times 10^{-4}]$
- Distribution direct result of sampling-based uncertainty analysis for all dose conversion factors
- Example: Dose (mrem/yr) to RMEI from  $^{99}\text{Tc}$  for igneous event at 10 yr that destroys all WPs (TSPA AMR Figs K6.6.1-9,-10)



DOTC99: 10,000 yr			
Step	Variable	R <sup>2</sup>	SRRC
1	MICTC99	0.29	0.57
2	INFIL	0.47	-0.43
3	SZGWSPDM	0.59	-0.33
4	SZFISPVO	0.64	-0.30
5	CSNFMAS	0.70	0.24
6	SZDIFCVO	0.72	0.13
7	KDRACOL	0.73	0.09



# References